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Two segmentation methods

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Two segmentation methods

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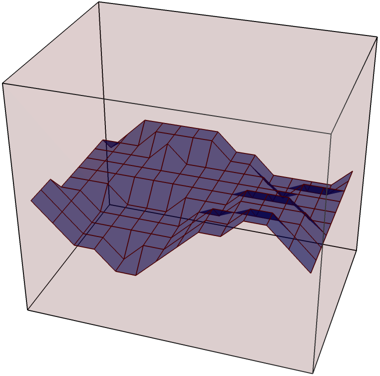
Presentation overview

- RoundCut: volumetric segmentation using mesh-based optimal graph search
  - (with Anders Bjorholm Dahl and Rasmus Larsen)
- Multiphase image segmentation using the deformable simplicial complex method
  - (with Asger Nyman Christiansen and Jakob Andreas Bærentzen)
- ... combining the two?

Optimal surface search



Problem

- 3D volume
- terrain-like surface
- smoothness constraint
- optimality

Solution[1,2]

- graph based
- allowing for a number of useful extensions (including RoundCut)

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[1] Xiaodong Wu and Danny Z Chen. Optimal net surface problems with applications. In *Automata, Languages and Programming*, pages 1029–1042. Springer, 2002

[2] Kang Li, Xiaodong Wu, Danny Z Chen, and Milan Sonka. Optimal surface segmentation in volumetric images-a graph-theoretic approach. *TPAMI*, 28(1):119–134, 2006

Algorithm fundamentals

Optimal net surface problem

- 3D volume, cost

$$c(x, y, z)$$

- terrain-like surface

$$z = S(x, y)$$

- smoothness constraint

$$|S(x, y) - S(x-1, y)| \leq \Delta_x$$
$$|S(x, y) - S(x, y-1)| \leq \Delta_y$$

- optimality

$$\min_S \sum_{x,y} c(x, y, S(x, y))$$

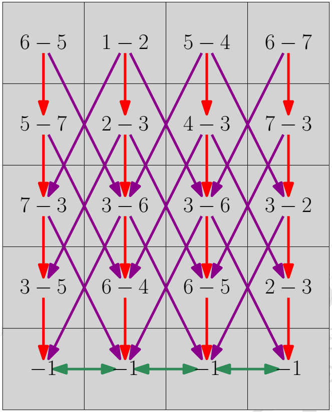
Minimum closed set problem (in a vertex weighted graph)

Minimum s-t cut problem (in an edge weighted graph)[3]

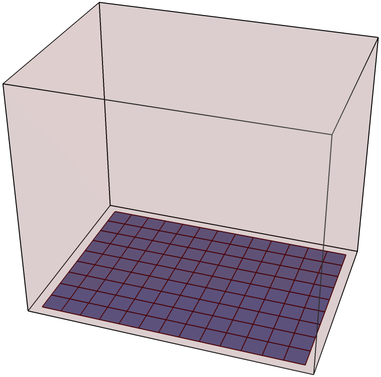
[3] Yuri Boykov and Vladimir Kolmogorov. An experimental comparison of min-cut/max-flow algorithms for energy minimization in vision. *TPAMI*, 26(9):1124–1137, 2004

Algorithm fundamentals

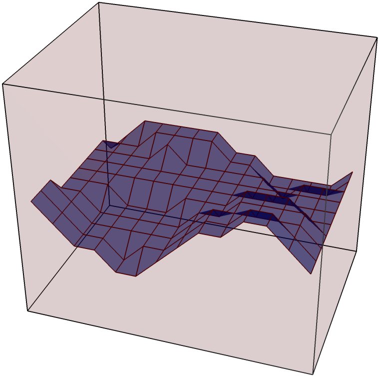
- 3D volume, cost
$$c(x, y, z)$$
- terrain-like surface:
base arcs, inter-column arcs
$$z = S(x, y)$$
- smoothness constraint:
intra-column arcs
$$|S(x, y) - S(x - 1, y)| \leq \Delta_x$$
$$|S(x, y) - S(x, y - 1)| \leq \Delta_y$$
$$\Delta_x = 2$$
- optimality:
weights
$$\min_S \sum_{x,y} c(x, y, S(x, y))$$



Terrain-like surfaces

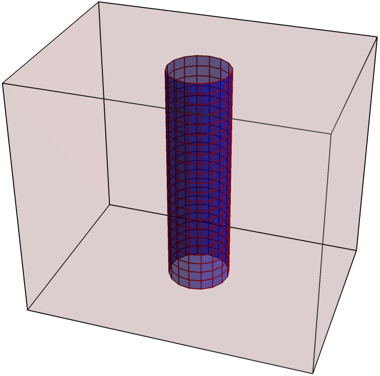


Base surface

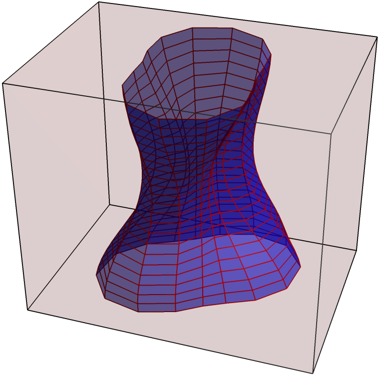


Realization

Tubular surfaces

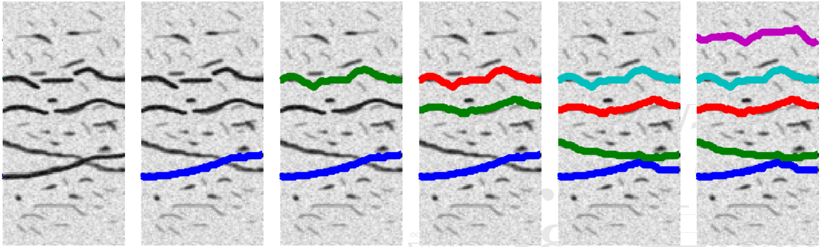


Base surface



Realization

Multiple interrelated surfaces



Extensions

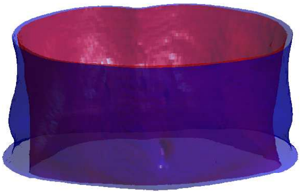
- In-region cost [4]
- Varying smoothness constraints [5]
- Shape and context priors [6]

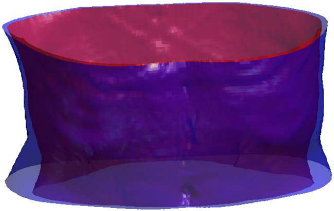
[4] Mona Haeker, Xiaodong Wu, Michael Abràmoff, Randy Kardon, and Milan Sonka. Incorporation of regional information in optimal 3-d graph search with application for intraretinal layer segmentation of optical coherence tomography images. In *Information Processing in Medical Imaging*, pages 607–618. Springer, 2007

[5] Mona Haeker, Michael D Abràmoff, Xiaodong Wu, Randy Kardon, and Milan Sonka. Use of varying constraints in optimal 3-d graph search for segmentation of macular optical coherence tomography images. In *MICCAI*, pages 244–251. Springer, 2007

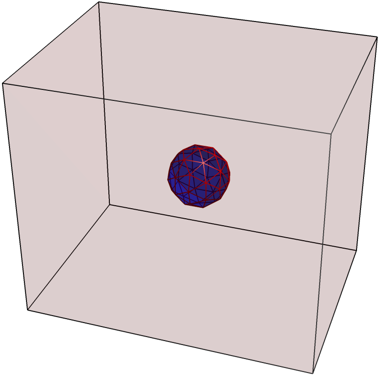
[6] Qi Song, Junjie Bai, M Garvin, Milan Sonka, J Buatti, and Xiaodong Wu. Optimal multiple surface segmentation with shape and context priors. *TMI*, 32(2):376–386, 2013

AbFat example

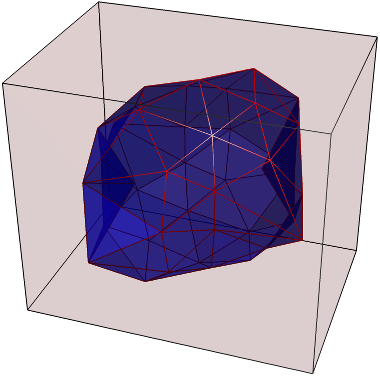




RoundCut



Base surface

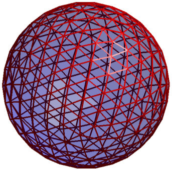


Realization

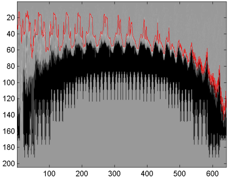
RoundCut basics

Approach related to:

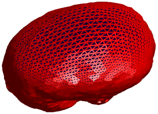
- NuggetCut[7]
- Radial ray based segmentation[8]



Initialization



Unwrapped image

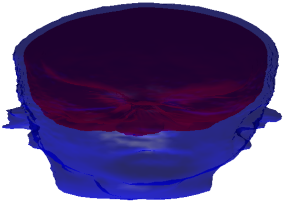


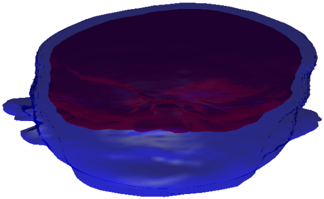
Solution

[7] Jan Egger, Miriam HA Bauer, Daniela Kuhnt, Barbara Carl, Christoph Kappus, Bernd Freisleben, and Christopher Nimsky. Nugget-cut: a segmentation scheme for spherically-and elliptically-shaped 3d objects.
In *DAGM Pattern Recognition*, pages 373–382. Springer, 2010

[8] Sebastian Steger, Nazli Bozoglu, Arjan Kuijper, and Stefan Wesarg. Application of radial ray based segmentation to cervical lymph nodes in ct images.
TMI, 32(5), 2013

ICV results

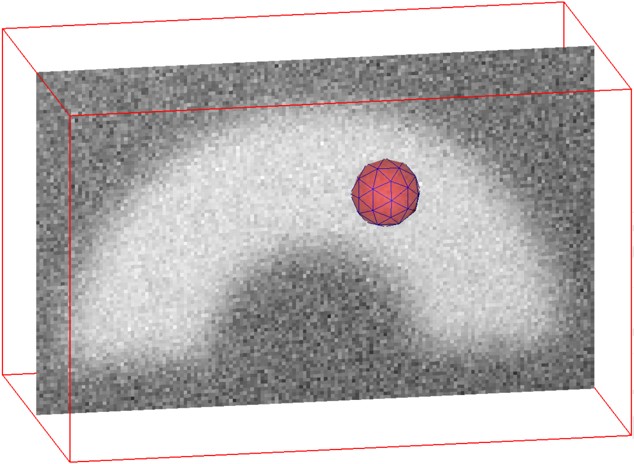




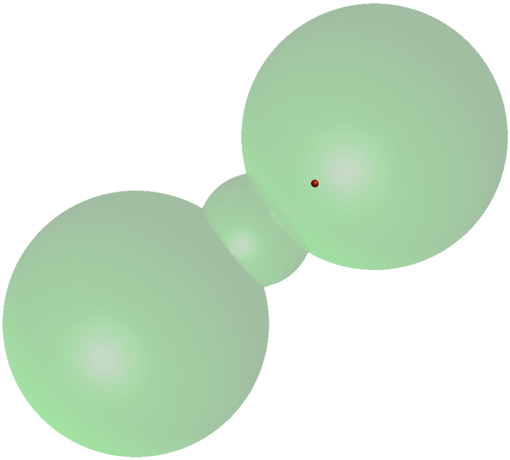
RoundCut

- Plus: generality, arbitrary topology and geometry
- Minus: loosing matrix representation
- Plus: hierarchical or iterative approach

Iterative RoundCut: beyond the star domain



Iterative RoundCut: beyond the star domain



Many challenges and a few solutions

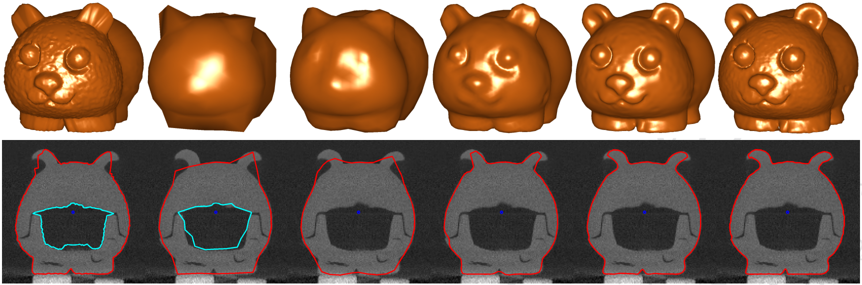
- Folding when normal sampling (gradient vector flow[9]? flow lines[10]? mesh smoothing?)
- Applicability of the smoothness constraint
  - Irregular mesh (adaptive sampling rate? mesh optimization?)
  - Accumulation of differences (mesh smoothing?)
- Handling interrelated surfaces (maintaining correspondence?)
- Explicit mesh processing
  - Mesh subdivision (Loop and butterfly)
  - Mesh smoothing (implicit and explicit Laplacian smoothing)

[9] Christian Bauer, Shanhui Sun, and Reinhard Beichel. Avoiding mesh folding in 3d optimal surface segmentation.
In *Advances in Visual Computing*, pages 214–223. Springer, 2011

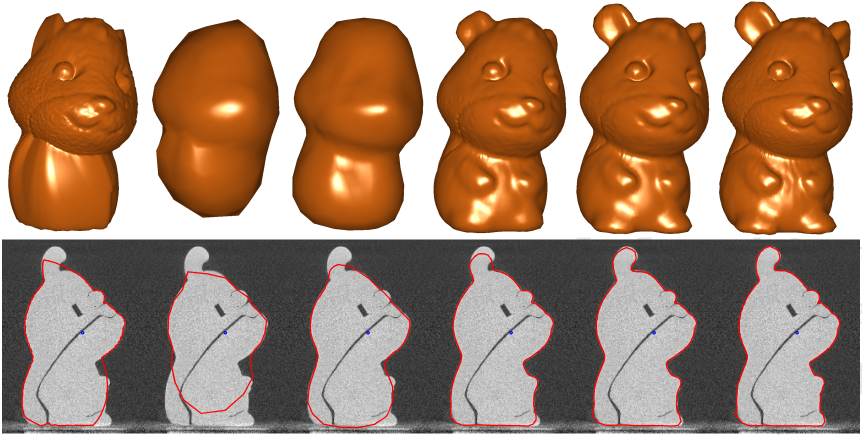
[10] Jens Petersen, Mads Nielsen, Pechin Lo, Zaigham Saghir, Asger Dirksen, and Marleen De Bruijne. Optimal graph based segmentation using flow lines with application to airway wall segmentation.
In *Information Processing in Medical Imaging*, pages 49–60. Springer, 2011

Micro-CT scan

Micro-CT scan



Micro-CT scan



Segmentation using the deformable simplicial complex method

The deformable simplicial complex method

- generic method for tracking deformable interfaces (curves in 2D, surfaces in 3D)
- implementational details and 3D version [11]
- applications in fluid simulation [12, 13]
- application in topology optimization [14]

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[11] Marek Krzysztof Misztal and Jakob Andreas Bærentzen. Topology-adaptive interface tracking using the deformable simplicial complex.
ACM Transactions on Graphics (TOG), 31(3):24, 2012

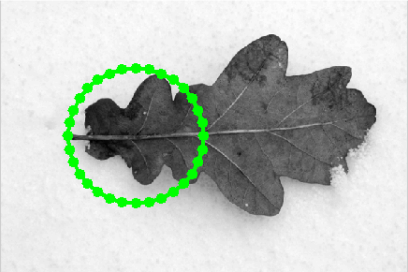
[12] Marek Krzysztof Misztal, Robert Bridson, Kenny Erleben, Jakob Andreas Bærentzen, and François Anton. Optimization-based fluid simulation on unstructured meshes.
In *VRIPHYS*, pages 11–20, 2010

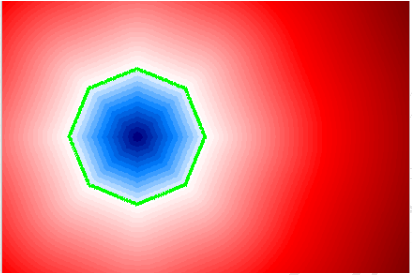
[13] Marek Krzysztof Misztal, Kenny Erleben, Adam Bargteil, Jens Fursund, B Christensen, Jakob Andreas Bærentzen, and Robert Bridson. Multiphase flow of immiscible fluids on unstructured moving meshes.
In *Proceedings of the ACM SIGGRAPH/Eurographics Symposium on Computer Animation*, pages 97–106. Eurographics Association, 2012

[14] Asger Nyman Christiansen, Morten Nobel-Jørgensen, Niels Aage, Ole Sigmund, and Jakob Andreas Bærentzen. Topology optimization using an explicit interface representation.
Structural and Multidisciplinary Optimization, pages 1–13, 2013

Deformable models for image segmentation

- Curves or surfaces that can move under:
  - internal forces (smoothness or other prior info)
  - external forces (image or volume data)
- Depending of the representation of the interface:
  - parametric deformable models, explicit interface (Lagrangian)
  - geometric deformable models, implicit interface (Eulerian)





ImSeg 2DDSC application

Features:

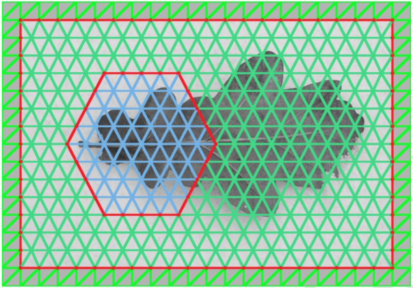
- Explicit curve tracking (advantages: boundary length, volume and size estimation)
- Adaptive topology (or not!)
- Multi phase
- Currently: region based external force [15], [16]

[15] Tony F Chan and Luminita A Vese. Active contours without edges. *IEEE Transactions on Image Processing*, 10(2):266–277, 2001

[16] Andy Tsai, Anthony Yezzi Jr, and Alan S Willsky. Curve evolution implementation of the Mumford-Shah functional for image segmentation, denoising, interpolation, and magnification. *IEEE Transactions on Image Processing*, 10(8):1169–1186, 2001

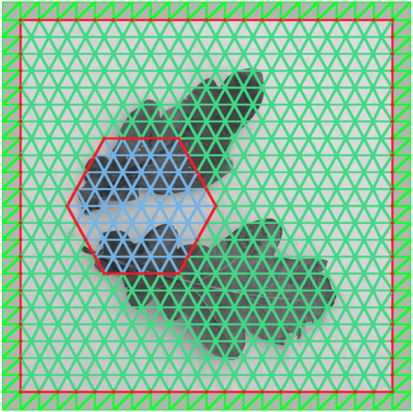
DSC segmentation

- DSC interface tracking



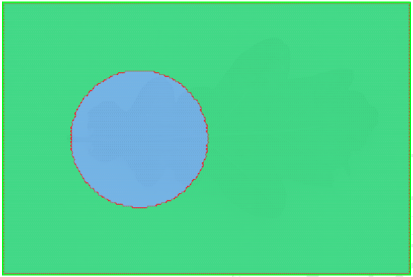
DSC segmentation

- Adaptive topology



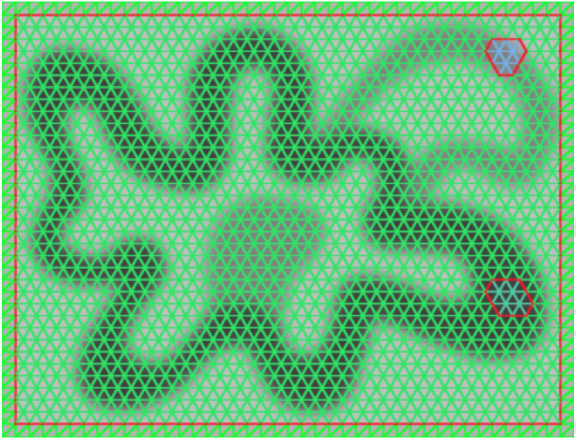
DSC segmentation

- Level of detail



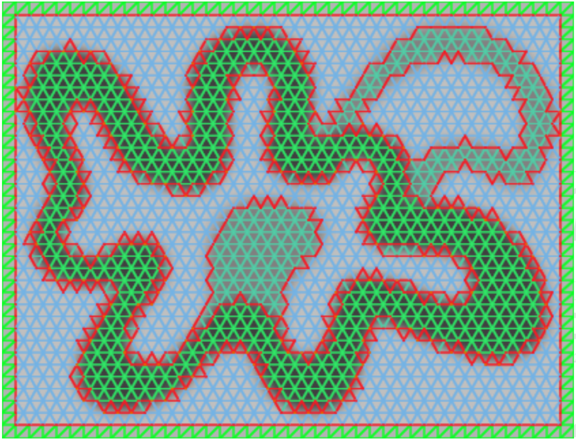
DSC segmentation

- Multi phase support



DSC segmentation

- Level of detail



Challenges

- Two-phase region force

$$\mathbf{F}_{\mathrm{ext}}(\mathbf{X}) = (m_{\mathrm{out}} - m_{\mathrm{in}})(I - m_{\mathrm{out}} + I - m_{\mathrm{in}})\mathbf{N}$$

  and multiphase region force

$$\mathbf{F}_{\mathrm{ext}}(\mathbf{X}_{ij}) = \frac{I - m_i + I - m_j}{m_i - m_j}\mathbf{N}_{\mathbf{ij}}$$

- Forces on tripple junctions and other crossings
- Criterion for explicit topology change
- Regularization vs. DSC optimization
- Formalization in variational method framework: minimizing Mumford-Shah functional.
- 3D!

Thank you!